NRAP Phase II Tools and Workflows

at the 2021 GWPC Annual Forum

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National Risk Assessment Partnership

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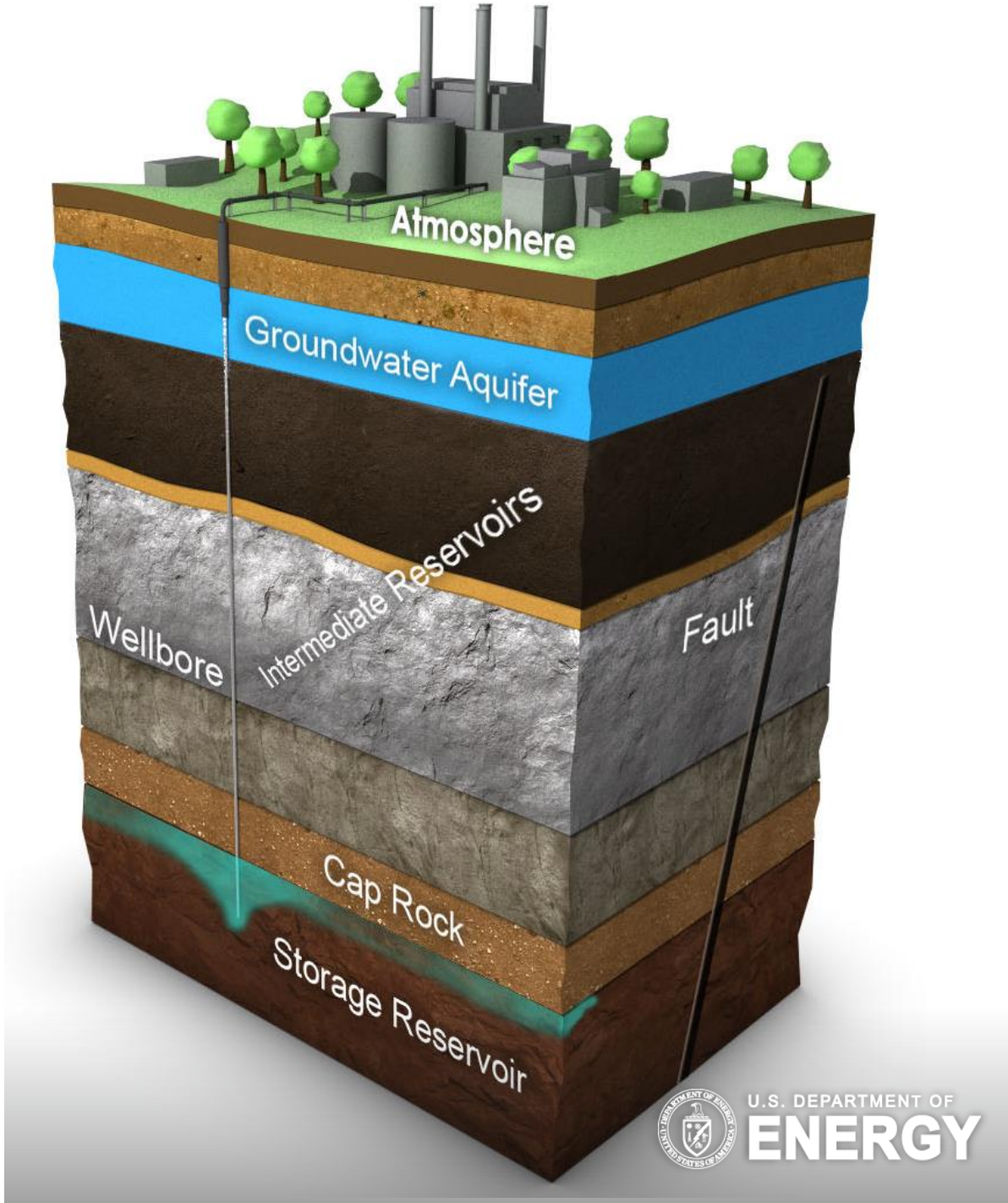

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Short term seismic forecasting – a tool to assess seismicity during injection operations and the RiskCat tool

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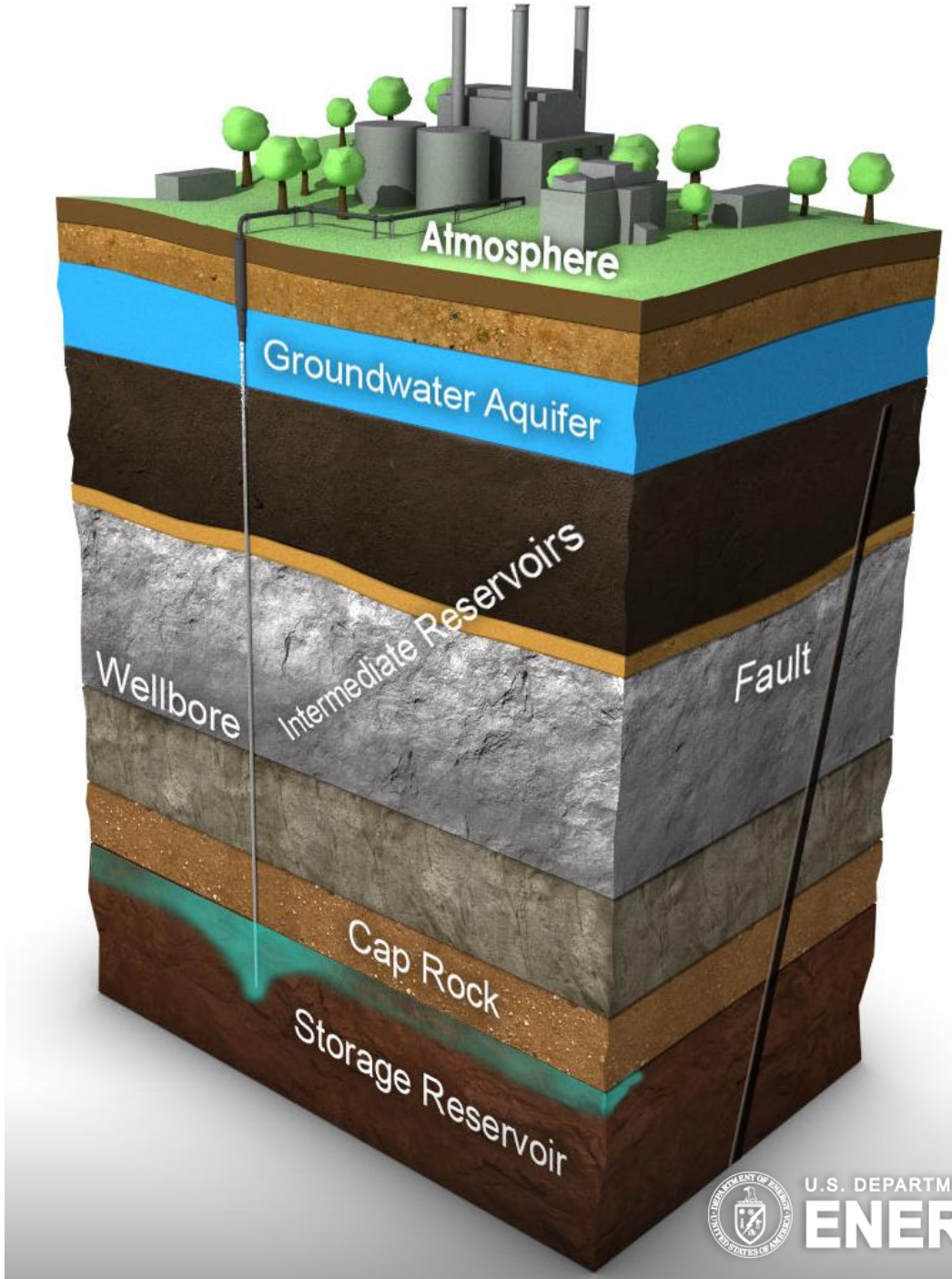

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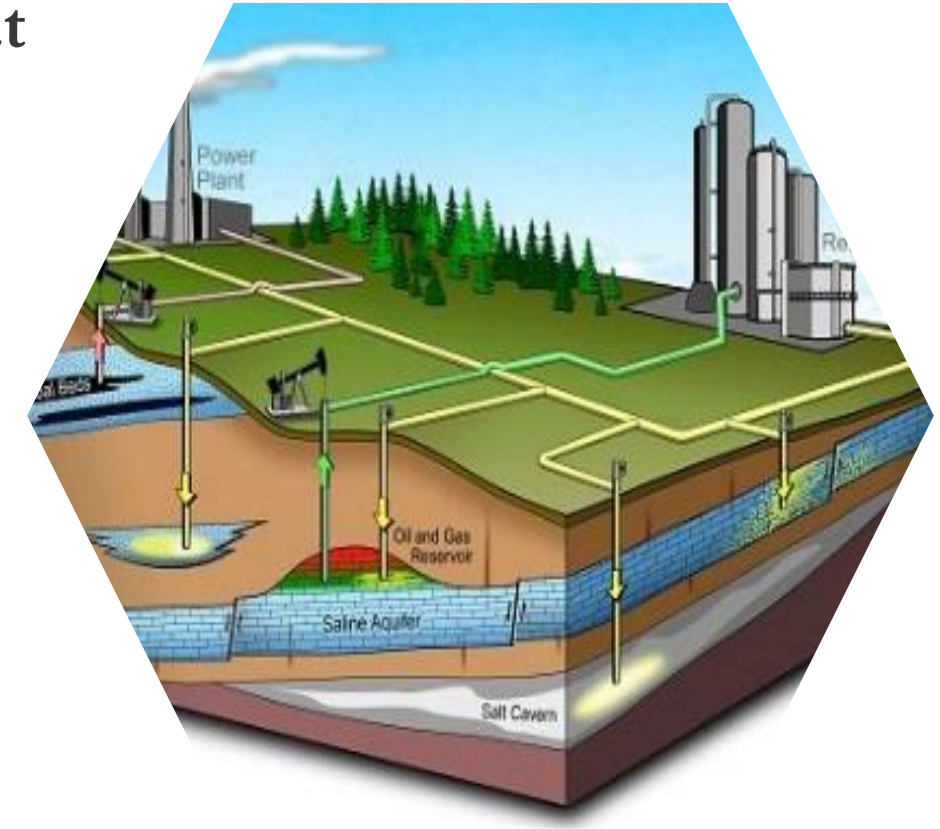
Overview

- **Introduction to both STSF and RiskCat**
  - Tools in a Nutshell
  - Background and Context
- **How to run to the tools**
  - Input / Output
  - Challenges
- **Examples**



Short Term Seismic Forecasting tool - in a Nutshell

Use observed earthquake catalogs and measured (and/or controllable) injection parameters to forecast earthquake rates

RiskCat tool – in a Nutshell

Use earthquake catalogs – observed or calculated - to determine seismic hazard and risk over the project lifetime

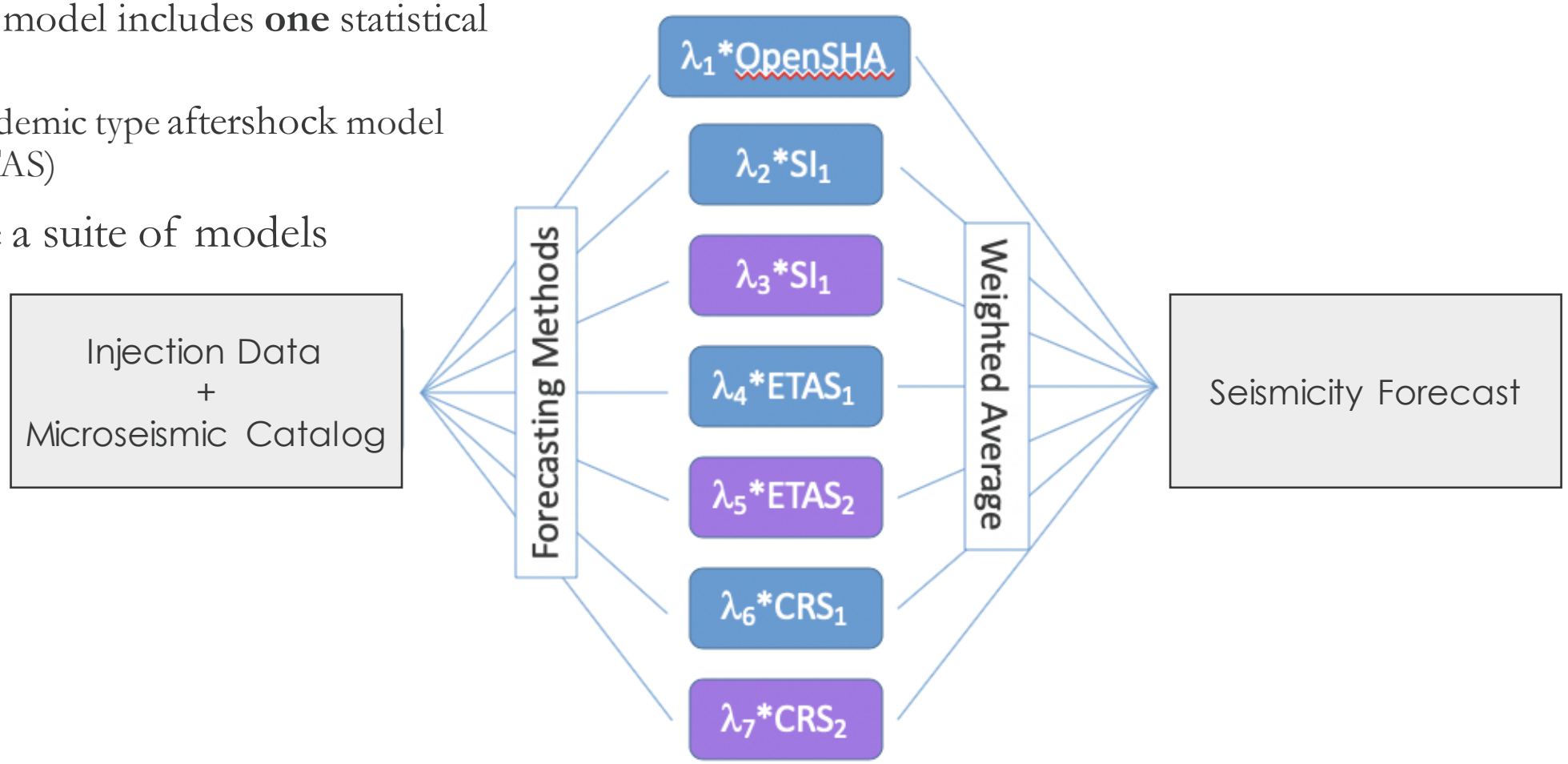
STSF – Background

- **Traditionally, induced seismicity projects are monitored with a traffic light systems (TLS)**
  - Reacts to single incidents like:
    - Recorded seismic events above threshold
    - Measurement of acceleration / ground motion above threshold
    - Public response
- **New system that incorporates all recorded seismicity**
  - Adapt established seismic model to induced seismicity
  - Incorporate injection parameter to calculate influence on rates

STSF – Future

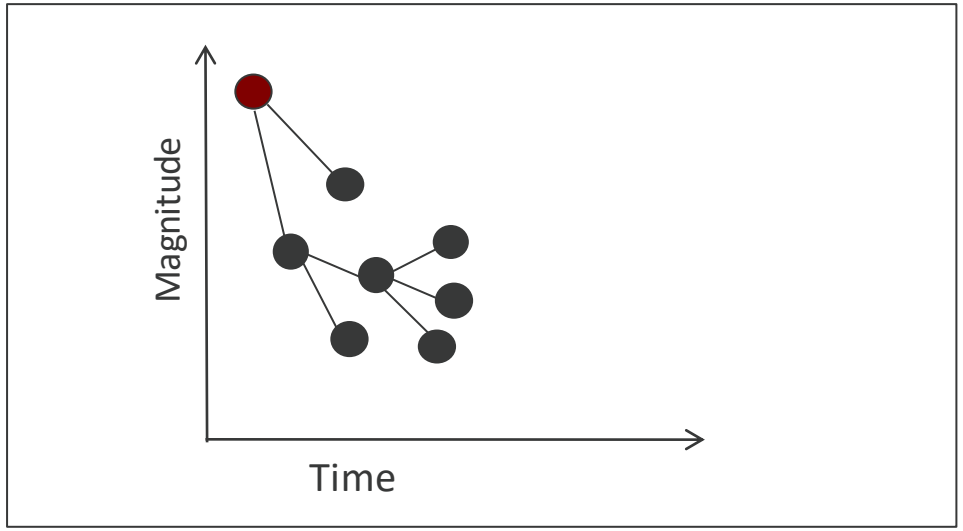
New release planned for end of Phase II

- Current model includes **one** statistical model
  - Epidemic type aftershock model (ETAS)
- Include a suite of models



STSF – Seismic Model

- **Epidemic Type Aftershock Sequence Model (ETAS)**
- **Originally developed by Ogata in 1988 to determine the occurrence of aftershock after a main shock / large event.**
  - Each earthquake has the ability to trigger aftershocks
  - ETAS is a cascading model



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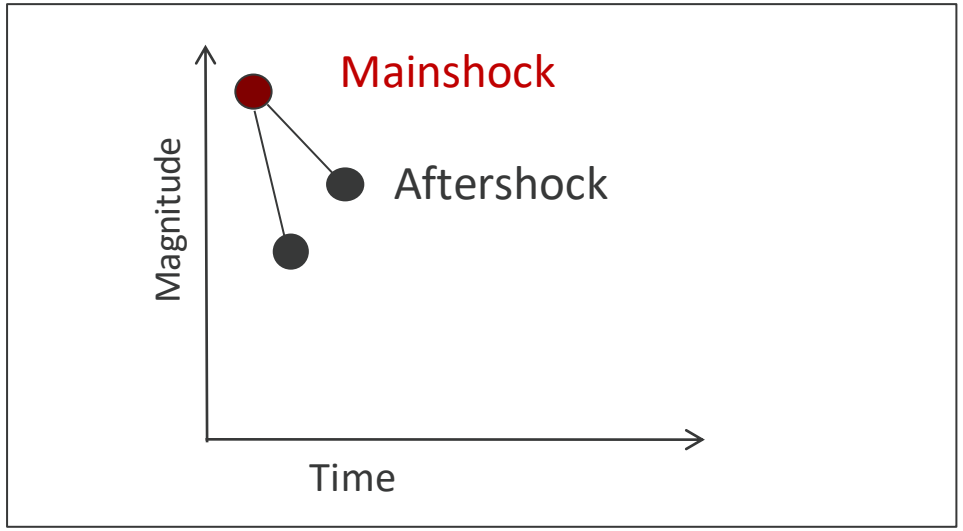

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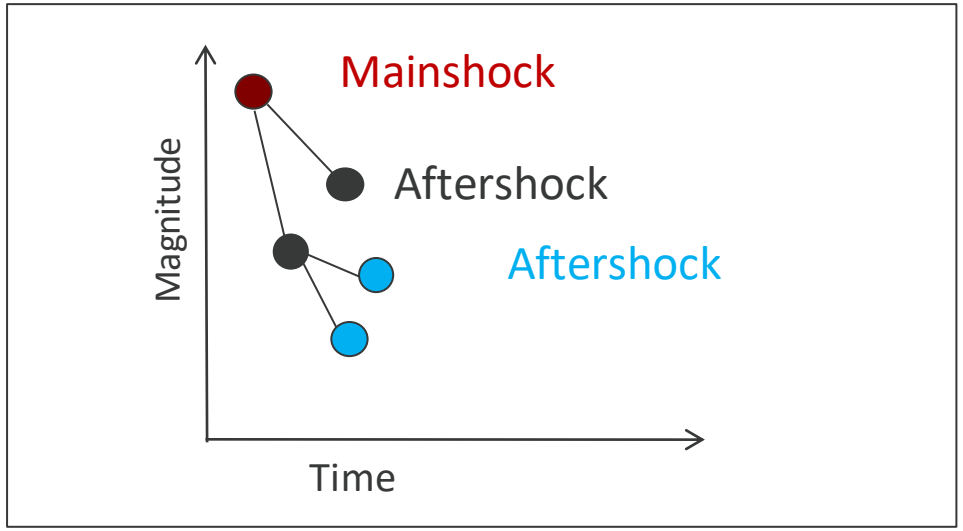

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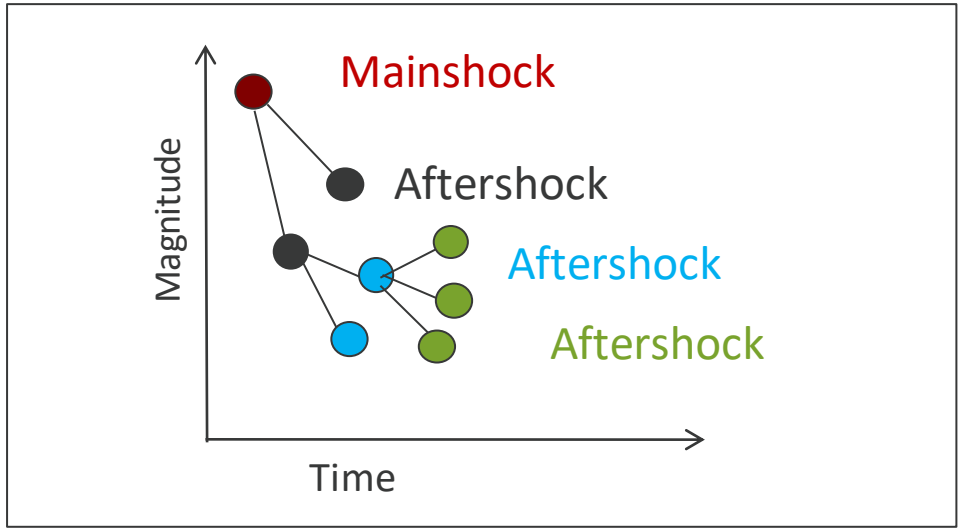
    - Mainshock triggers aftershocks
      - Aftershocks can trigger aftershocks
    - After and mainshock are purely temporal terms. If aftershocks are larger than main shocks, there is often a re-classification to foreshock / mainshock.



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K, α = productivity parameters
c = delay term (time)
p = decay term

$$\lambda_i(t) = \frac{K}{(c + t - t_i)^p} 10^{\alpha(M_i - M_{\min})}$$

$$\lambda(t) = \lambda_0 + \sum_{[i:t<t_i]} \lambda_i(t)$$

Background Term
- Describes natural / background seismicity

Triggered Term
- Describes increase in seismicity due to disturbance

STSF – Seismic Model

- **To adapt for injection induced seismicity, a term is added into the background:**

$$\lambda_0(t) = \mu + c_f \times F_r(t)$$

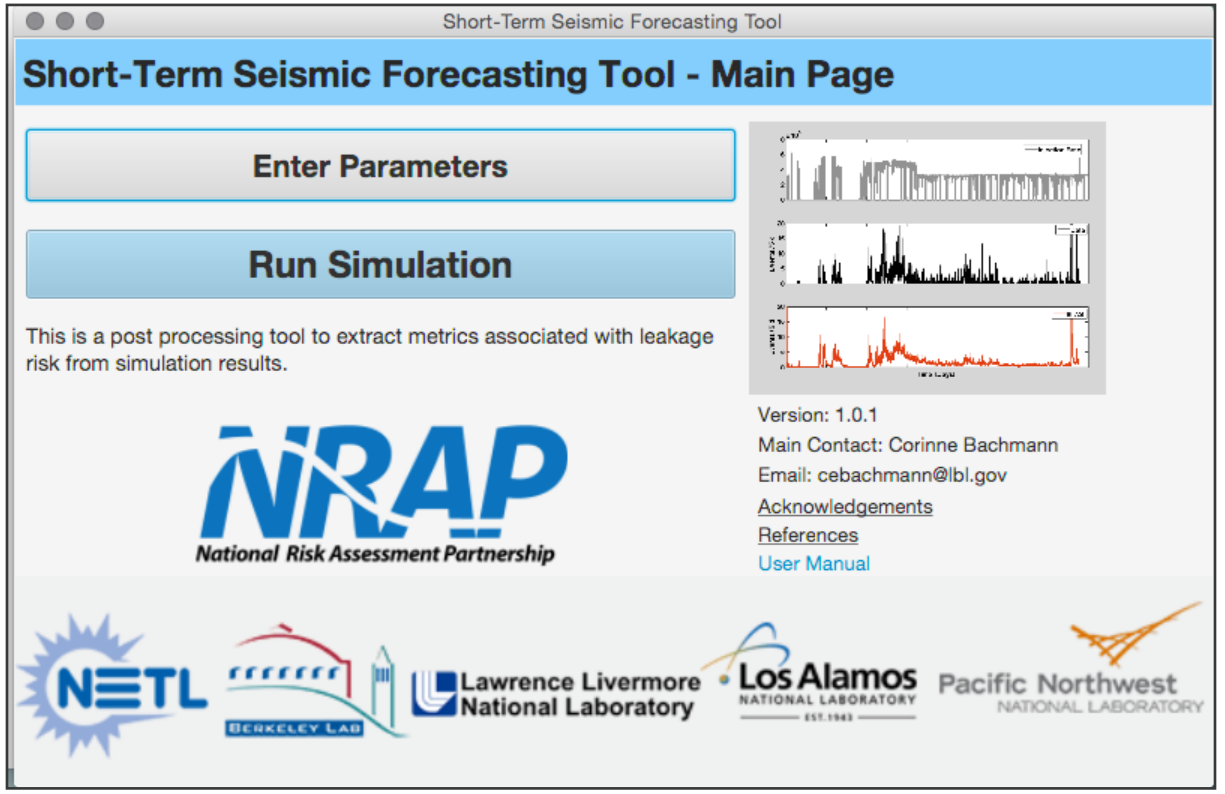
- **c*f* is a scale parameter**
- ***Fr(t)* is a measured injection parameter**
  - Can be the injection rate, measured pressure etc.
  - When using a parameter that can be changed by the operator, different scenarios can be calculated
    - Earthquake rate if injection rate doubles?
    - Earthquake rate if injection rate is reduced by half?

STSF – Tool installation

- https://edx.netl.doe.gov/nrap/short-term-seismic-forecasting-stsf/
- **The tool package is a zip file**
  - Unpacking the zip file creates a folder with all files needed
- **Currently only tested on Mac OSX and Linux**
  - Currently not supported under Windows
- **Requires Java Runtime Environment (JRE) version 8 update 40 or newer**
- **Requires gcc and Perl**

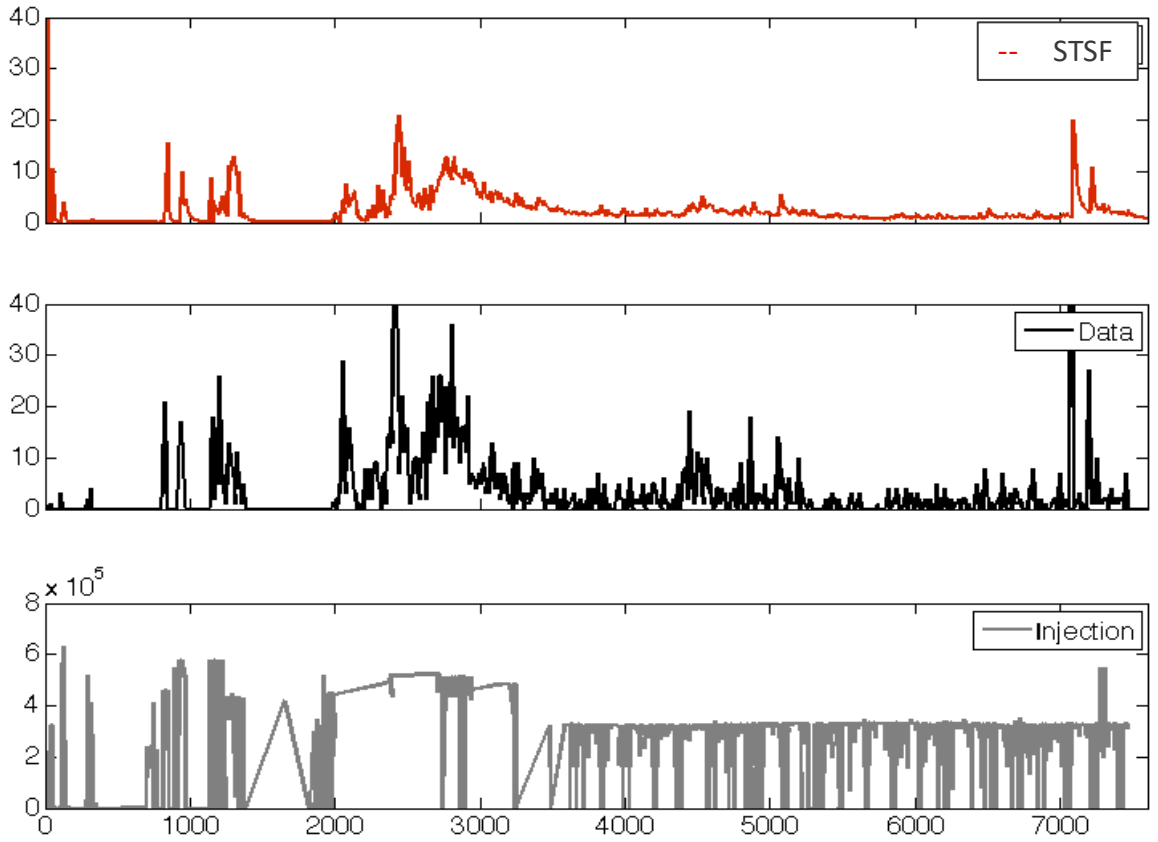
STSF – Running the tool

- **To run the GUI**
  - sh bin/application
- **Enter parameters will prompt a new window where all parameters are picked**
  - Parameters are described in manual
  - Support for parameters in the EDX forum (link at the end)
- **Run Simulation runs one simulation with chosen parameters and writes output files**



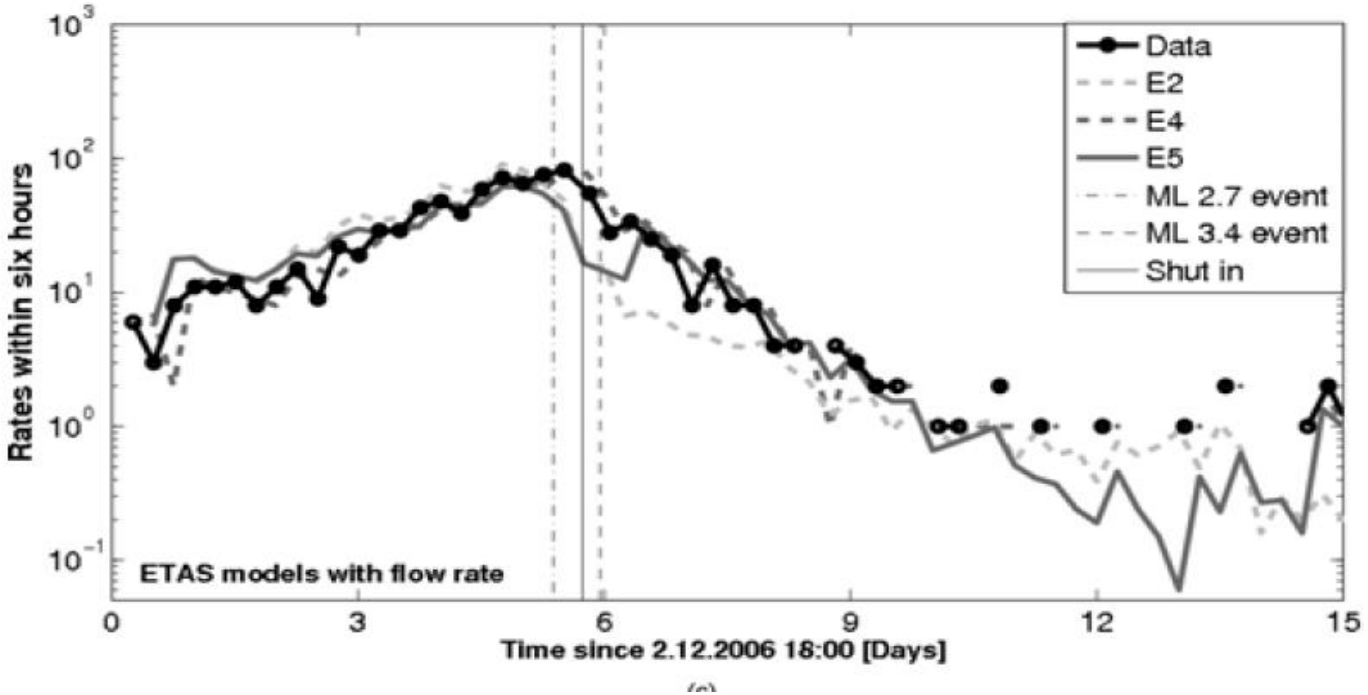
STSF – Examples – Paradox Valley

- **Brine water injection over 20 years**
- **Relatively remote area in Colorado**
  - Earthquake rate per five days
  - Different injection periods lead to different seismicity in the early stages
  - STSF underrepresents changes in seismicity during constant injection
  - STSF models late changes due to large events



STSF – Examples – Basel, Switzerland

- **EGS project, injection for six days before TLS triggered reduction and shut in**
- **Urban area in Switzerland**
  - Earthquake rates for 1/4-day
  - E2,E4 and E5 are different realizations of the model
    - Different fixed and varying variables that are described in the manual



STSF – Challenges and limitations

- **Tool is not designed to work as a site characterization before injection**
  - Minimum number of events is needed
- **Tool relies on seismic event data**
  - Seismic network with high detection rate / low magnitude of completeness
  - Seismically inactive injection might not provide enough data
- **Tool has not yet been applied to an area in real time**
  - Only pseudo real time testing after project was complete or was in operation for a long time already

RiskCat – Background

- Developed as a collaboration between LLNL, LBNL and an independent contractor
- Makes no assumptions about the time and space distribution of seismicity, can accommodate any type of time and space non-stationarity
- Uses simulated or recorded seismic catalogs as input

➢Induced seismic hazard and risk very well suited as it his highly non-stationary

RiskCat – Installation

- **The RiskCat code is on gitlab**
  - https://gitlab.com/NRAP/RiskCat

- **Unlike other NRAP tools, RiskCat is not a GUI**
  - More suited for non-lay users
- **Install is described in the readme file**
  - The 'make' file includes the whole installation
  - Only tested on linux and Mac computers

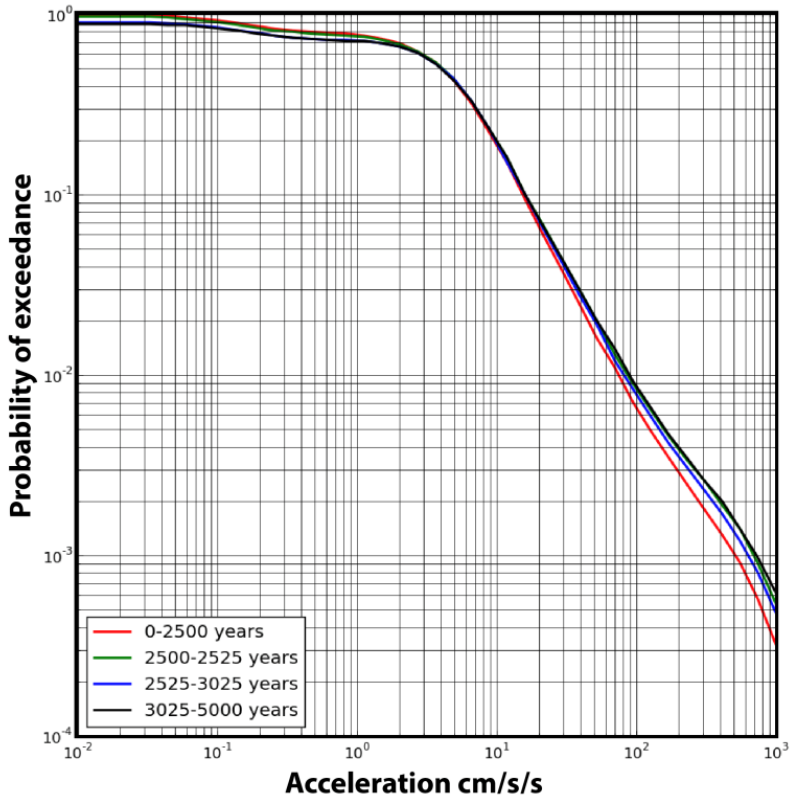
RiskCat – Running the tool

- **../riskcat KingIS.menu will run the example file**
- **Example file will create hazard and risk output for a subset of a simulation for King Island**
  - Example run will both save files and PDF files with example curves
- **Results are saved in the EQSimrisk folder**
- **The manual explains all input parameters in depth and how to manipulate them**
  - Manual still work in progress and will be updated in the next phase

RiskCat – Examples / Hazard

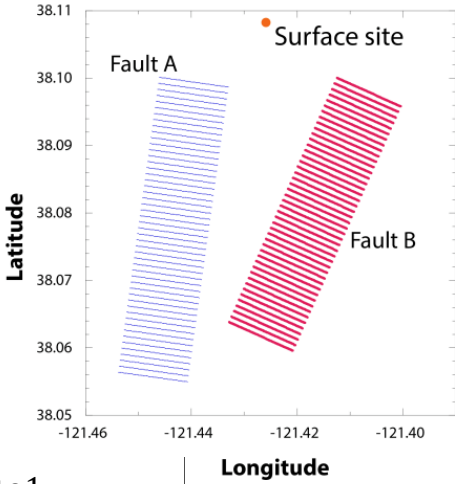
- **Based on a simulation of induced seismicity**
  - Earthquake catalog with RSQsim
  - Injection with TOUGH2
- **Probability of exceeding a pre-defined acceleration threshold**
- **Four different time periods**
  - Pre (background)-, co-, post and late-post injection periods
  - Covers the whole project lifetime

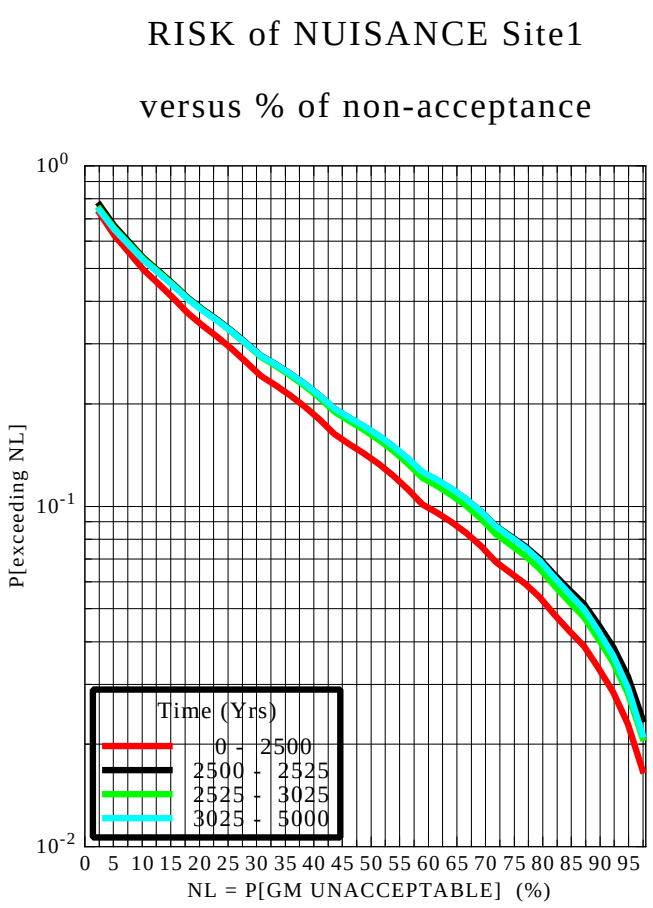
➢ **Difference most significant for largest accelerations**



RiskCat – Examples / Risk

- **Risk is for pre-defined surface site**
  - Site conditions need to be known
  - Population density and building stock is important
- **Risk of nuisance for the same four time periods as the last slide**
  - Nuisance indicates lower risks, but important for induced seismicity where public acceptance of the project is key
- **Nuisance risk is elevated for all levels over background (red)**





RiskCat – Challenges

- RiskCat is not a GUI like other tools
- Usage of RiskCat is not straightforward, especially for lay users
- Backward combability to work with other datasets is not always guaranteed
- Technical support is not always straightforward

Questions and Discussion

Thank you!

NRAP Website: https://edx.netl.doe.gov/nrap/

Sign up for NETL EDX: https://edx.netl.doe.gov/user/register

Support for the tools is available in an online forum

https://edx.netl.doe.gov/workspace/dashboard/nrap-tools